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Evaluation of the Performance of Cooling Boxes with Variations of Nacl Kcl and Tapioca Flour Solutions in Water as Energy Storage Media

Aja Nadia Sukma ✉**,** Universitas Malikussaleh, Indonesia
Adi Setiawan, Universitas Malikussaleh, Indonesia
Taufiq, Universitas Malikussaleh, Indonesia
Jumadi, Universitas Malikussaleh, Indonesia
Riza Andriani, Universitas Malikussaleh, Indonesia

✉ *aja.200750003@mhs.unimal.ac.id*

Abstract: This study aims to determine which solution between NaCl, KCL, and tapioca starch shows the best performance in the charging and discharging process and to determine which solution is optimal between NaCl, KCL, and tapioca starch in maintaining the temperature longer. This study uses an experimental method, each material is tested using 10% solution through the process of releasing heat energy charging and absorbing heat energy discharging. The solution is frozen for 12 hours in a PCM bottle, then tested in a refrigerated box for 12 hours, with temperature monitored at several points. Data collection uses test techniques to see temperature changes in the charging and disharging testing process in the cooling box. Data analysis uses descriptive statistical analysis, which is carried out in the form of tables, images, graphs, and data presentations. The results showed that in the charging process NaCl experienced the fastest temperature drop reaching -16°C, NaCl also experienced a stable temperature increase of up to 11°C between KCl and tapioca flour. Meanwhile, in the discharging process, KCl is slower in decreasing the temperature to -11.8°C and experiencing a faster temperature increase to 24.2°C. The optimal solution of NaCl, KCl, and tapioca flour in maintaining a longer temperature is, tapioca flour is better because it can maintain a more stable and durable temperature than KCl and NaCl.

Keywords: Cooler Box, NaCl, KCl, Tapioca Flour, Charging, Discharging.

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INTRODUCTION

Cooler boxes are a very important device in various industries, especially in the food, pharmaceutical and logistics sectors. Its main function is to keep the product at a low temperature so that the quality and safety of the product can be maintained during storage or transportation. In the context of the cold chain, the performance of the cooler box is crucial, as failure to maintain the desired temperature can result in significant losses both in terms of economy and product quality. One of the important components in a cooler box is the energy storage medium used to absorb and store heat.

One of the important components in a cooler box is the energy storage medium used to absorb and store heat. These media must be able to maintain low temperatures for long periods of time to ensure the product remains in optimal condition. The use of water as a cooling medium is often less effective due to its limited heat storage capacity. Therefore, there is a need to improve the performance of coolers through the development of more efficient energy storage media.

The refrigerant used is by adding certain substances to the water to increase the energy storage capacity. That is, variations of solutions such as NaCl (Sodium Chloride) and KCl (Potassium Chloride) are known to lower the freezing point of water and increase latent heat capacity, making it more effective in maintaining low temperatures. On the other hand, natural ingredients such as tapioca flour can form gels in water that are able to absorb and store heat energy effectively.

The advantages of the 3 solvents are. NaCl is a very inexpensive and readily available material, making it an economical choice for refrigeration systems. NaCl is also effective in lowering the freezing point of water, improving the performance of the cooler especially in very cold conditions. Nacl has a fairly good specific heat capacity. Tapioca flour The gel consistency or slurry of tapioca flour can be adjusted as needed which provides flexibility in the design of the cooling system. Tapioca flour is safe and harmless to human health. Tapioca flour has a good specific heat capacity, making it efficient in storing and releasing energy.

However, the effect of variations of these materials on the performance of cooler boxes has not been studied in depth. Research conducted by Sucipta et al (2023) has shown that incorporating refrigerants such as NaCl, into water can significantly increase energy consumption by up to 73% compared to pure water, thereby improving the efficiency of heat energy storage. In addition, the use of endothermic salts in refrigeration systems such as potassium chloride. It lowers the temperature by up to 12.3°C, suggesting that it can have a significant cooling effect when dissolved in water.

Research conducted by Alief et al., (2024) technically KCl/H2O is effective in reducing fish temperature by -0.22°C/minute. The use of 2 kg KCl/H2O is effective in maintaining the temperature of fish in the temperature range of 0 to 5°C for 20 hours and the use of 3 kg of KCl/H2O is good in maintaining the temperature of fish in a lower temperature range of -5 to 0°C for 16 hours. The combination of thermoelectric refrigerant and fatty acids as PCM in portable box coolers shows promising results in extending temperature maintenance time, demonstrating the effectiveness of these materials in energy storage applications.

Phase Change Material (PCM) is a material that is capable of storing and releasing energy in the form of latent heat when undergoing phase changes, usually between the solid and liquid phases. PCMs are used in a variety of applications to store and regulate thermal energy, including in cooling, heating, and energy management systems in buildings. PCM works by absorbing heat as the ambient temperature increases, causing the PCM to melt from solid to liquid. Conversely, when the ambient temperature decreases the PCM releases the stored heat as it re-hardens from liquid to solid. This process allows the PCM to keep the ambient temperature stable at its specific melting temperature. Determining the optimal solution of NaCl, KCl, and tapioca flour in water is an important step to maximize the efficiency of the cooler. Variations in the solution can affect the thermal properties of the solution, including the drop in freezing point, heat capacity, and energy release time, which will ultimately affect the overall performance of the cooling box.

Based on the background of the above problems, the researcher considers that the evaluation of the performance of the cooling box is very important to be carried out because to see which solution is more effective in maintaining cold temperatures. Therefore, the researcher is interested in evaluating the performance of the cooling box with a variety of solutions of NaCl, KCl and tapioca flour in water as an energy storage medium.

METHODS

This study uses an experimental method. According to Sugiyono (2019) stated that the experimental method is one of the quantitative methods, this research method is by making observations to find quantitative data in a process through research so that it can find out the effectiveness of this research. The material used in this study is a cooling box with a variety of solutions of NaCl, KCl, and tapioca flour in water as an energy storage medium.

The data collection technique in the study aims to see temperature changes in the charging and discharging process with a predetermined sensor point for a period of 12 hours. Data analysis uses tests on cooler boxes, data presentation is carried out with descriptive statistics, which are carried out in the form of tables, images, graphs, data presentations. In this study, these three variables are used, namely, fixed variables, independent variables, and bound variables.

Table 1. *Sample Codes*

It	Sample Code	Description	Time (hours)
1.	PCM-N	10% NaCl solution in water	12
2.	PCM-K	10% KCl solution in water	12
3.	PCM-T	10% PCM-T solution in water	12

Source: Researcher (2024)

RESULTS

In this sub-chapter, the results of the test of solution variations in the charging and discharging processes that occur in the cooling box will be discussed. This test process aims to evaluate the effectiveness of each type of solution used as a phase change material (PCM) in absorbing and releasing heat. The charging test is carried out by measuring the temperature drop when the PCM absorbs heat from the environment, while the discharging test is carried out by measuring the temperature increase when the PCM releases heat into the environment. The charging and discharging test on the cooling box consists of three tests, namely, the first test using PCM-N, the second test using PCM-K and the third test using PCM-T.

Charging and discharging tests on PCM-N

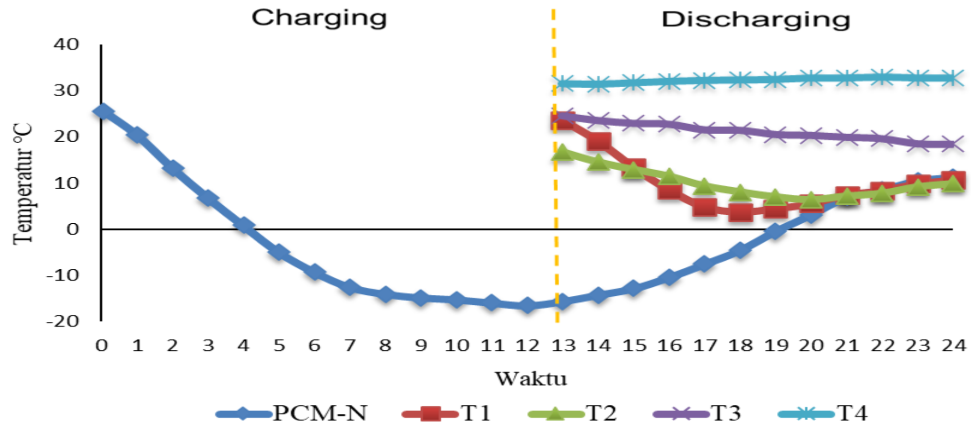

Figure 1. *Graph of Temperature Changes Relative to Time During Charging and Discharging Processes on PCM-N*
Source: Researcher (2024)

Information:

PCM-N :

T1 : Canned Drinks
T2 : In the Styrofoam Room
T3 : Styrofoam Outer Wall
T4 : Environment

Charging and Discharging Test on PCM-K

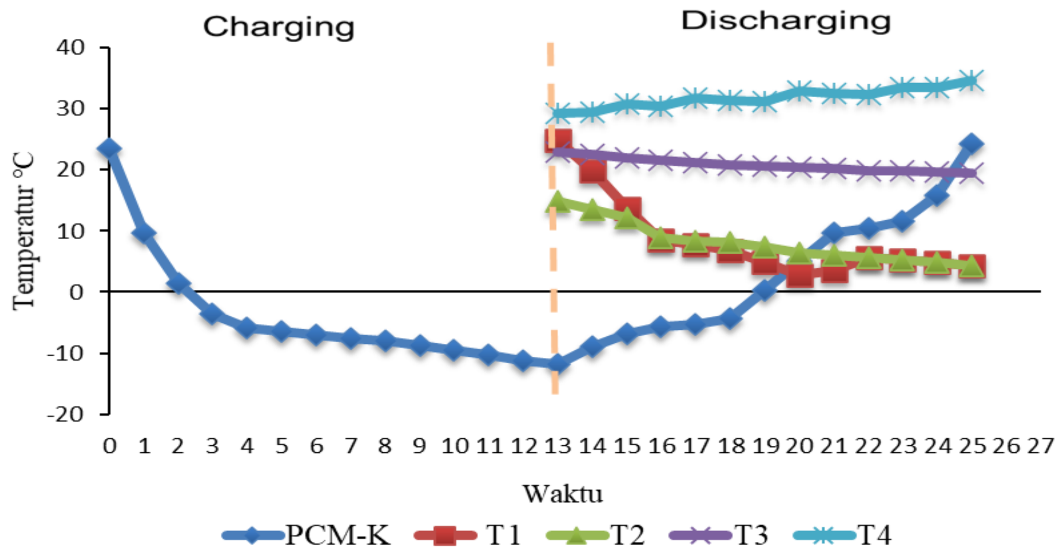

Figure 2. *Graph of Temperature Changes Relative to Time During Charging and Discharging Process on PCM-K*
Source: Researcher (2024)

Information:

PCM-K :

T1 : Canned Drinks
T2 : In Space Styrofoam
T3 : Styrofoam Outer Wall
T4 : Environment

Charging and Disharging Test on PCM-T

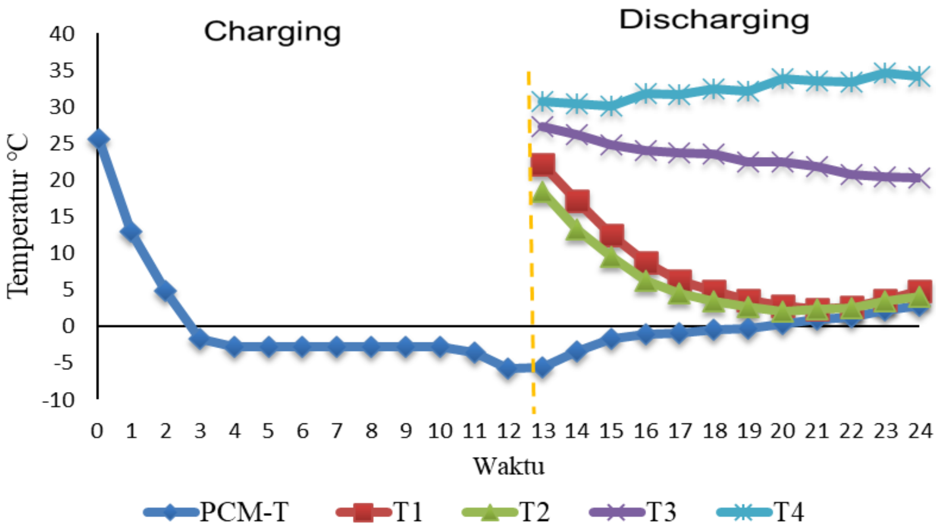

Figure 3. *Graph of Temperature Changes Relative to Time During Charging and Discharging Process on PCM-T*
Source: Researcher (2024)

Information:

PCM-T :
T1 : Canned Drinks
T2 : In Space Styrofoam
T3 : Styrofoam Outer Wall
T4 : Environment

Table 2. *Temperature Change Test Record Data in Cooler Box*

Test Points			**Time (Hours)**	**Temperature (°C)**					
	It			**PCM-N**		**PCM-K**		**PCM-T**	
				Beginning	**End**	**Beginning**	**End**	**Beginning**	**End**
Sensor Position	1	*Charging*	12	29.6	-8.3	23.6	-11.3	27.4	-5.3
	2	*Dis Charging*	12	-8.3	24.5	-11.8	24.2	-5.3	26
	3	T1	12	26.3	-1.1	24.8	-4.3	30.8	2.5
	4	T2	12	1.3	10	-9.4	-4.4	-0.1	0
	5	T3	12	29.2	20.1	22.9	22.9	29.2	25.4
	6	T4	12	30.4	21.9	29.2	19.4	33.2	28.2

Information:

T1: Beverage Cans
T2: In Styrofoam Room
T3: Styrofoam Outer Wall
T4: Environment

Comparison of PCM-K, PCM-N and PCM-T Performance

The performance comparison of the three types of PCM (Phase Change Material) used, namely PCM-K, PCM-N and PCM-T will be analyzed based on the data from the energy storage charging and energy discharge discharging test results. This comparison is important to determine the most effective energy storage medium in maintaining low temperatures in the cooler.

Charging

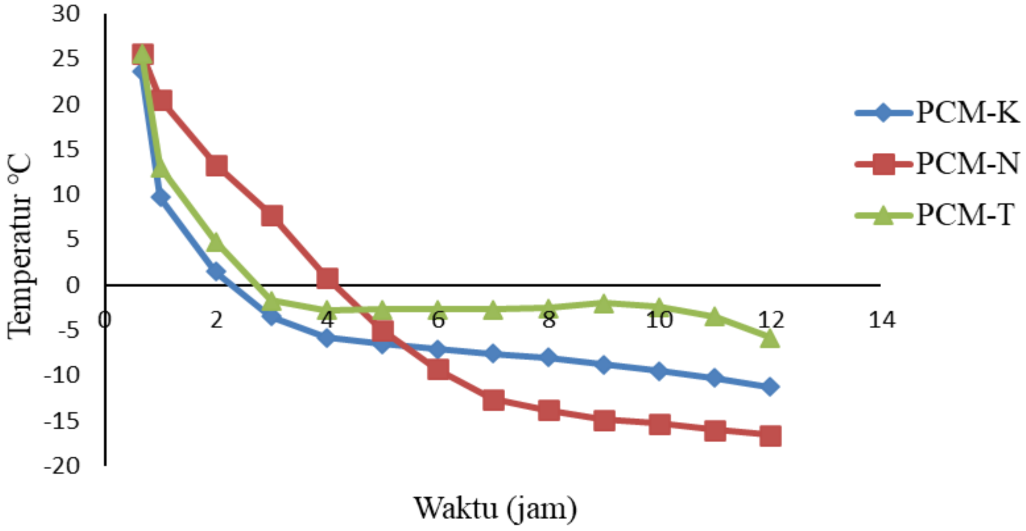

Figure 4. *Graph of Temperature Changes Relative to Time During the Charging Process by Using PCM-N, PCM-K and PCM-T*
Source: Researcher (2024)

Based on the test results in the charging comparison process on PCM-K, PCM-N, and PCM-T samples. As shown in Figure 4 Graph of temperature changes to charging time. These three PCMs show different rates of temperature decline over time, which can be used to describe the effectiveness of each PCM in maintaining or lowering the temperature over a given time. The initial temperature drop of 0-2 hours of the third PCM begins at 25-30°C. within two hours there is a drastic drop in temperature for all PCMs. PCM-N experienced the fastest decline, followed by PCM-K, and finally PCM-T. PCM-N reaches temperatures close to 0°C faster than other PCMs, showing a strong initial response in absorbing heat. At 2-8 hours, PCM-N experienced a significant temperature drop until it reached a temperature of around -15°C at the 6th hour, then stabilized at that temperature. PCM-K declined more slowly than PCM-N and reached a temperature of around -10°C at 8 o'clock, but then underwent slight changes. However, PCM-T maintains temperatures between 0°C and -5°C after the initial drop, exhibiting stability at higher temperatures than PCM-K and PCM-N. At 8-12 hours after the 8th hour, PCM-K and PCM-N exhibit stability at their respective low temperatures, with PCM-N at around -15°C and PCM-K at around -10°C. PCM-T remains at around 0 to -5°C, indicating that the material does not reach temperatures as low as PCM-K and PCM-N, but exhibits better stability over this temperature range.

This explains that PCM-N absorbs heat quickly and reaches lower temperatures in a short time, making it suitable for applications that require rapid cooling to very low temperatures. PCM-K achieves lower temperatures but with a slower rate of drop, making it suitable for applications that require a gradual decrease in temperature. PCM-T remains stable at temperatures below 0°C and exhibits a slower temperature drop, making it suitable for applications that require stable temperatures.

These results are in line with research by Smith et al. (2022) which showed that NaCl has better cooling ability compared to KCl and tapioca flour because NaCl has higher thermal conductivity. This means that NaCl can conduct heat more effectively than KCl and tapioca flour, so the heat absorption process is more efficient. With its higher thermal conductivity, NaCl is able to absorb and release heat faster, which increases its ability to cool things. This is especially important in applications that require fast and efficient temperature control.

Discharging

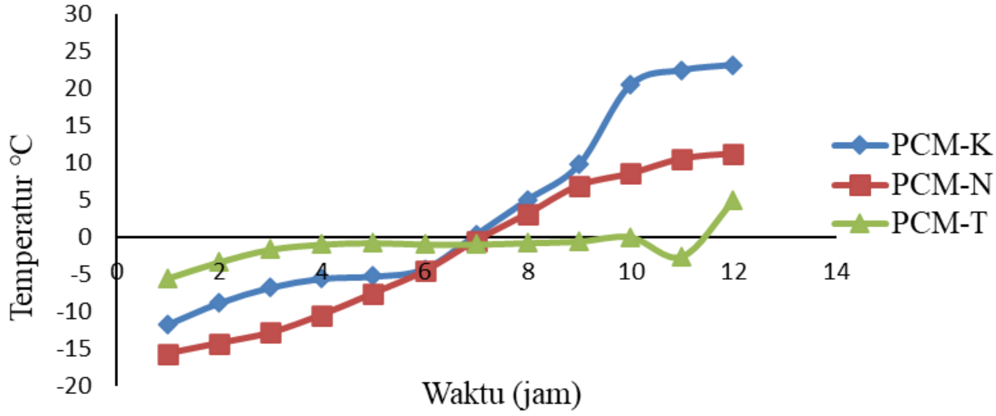

Figure 5. *Graph of Temperature Changes Relative to Time During Discharging Process Using PCM-N, PCM-K and PCM-T*
Source:Researcher (2024)

Based on the test results in the discharging comparison process on PCM-K, PCM-N, and PCM-T samples. As shown in Figure 5 the graph of temperature changes to the discharging time. This third PCM shows the comparison of temperature to time. At the beginning of 0-4 hours. Initially, all three PCMs (PCM-K, PCM-N, and PCM-T) were below 0°C, with PCM-N indicating the lowest temperature, which was close to -15°C. PCM-K and PCM-N experienced a steady increase in temperature until they reached a point close to 0°C in about 4 hours. PCM-T remains stable at around 0°C without experiencing many temperature changes. This indicates that PCM-T has better temperature stability around the freezing point in the initial phase. At medium time 4-8 hours. PCM-K and PCM-N continue to experience temperature increases despite at slower rates. PCM-K shows a faster temperature rise than PCM-N. PCM-T remains stable at around 0°C, which indicates its capacity to maintain temperatures close to freezing for longer durations than the other two PCMs.

Meanwhile, at the final temperature of 8-12 hours. In this period, PCM-K showed a significant increase in temperature after the 8th hour, reaching temperatures above 20°C at the 12th hour. PCM-N experiences a steady increase in temperature but not as fast as PCM-K, being around 5-10°C at the end of the period. PCM-T begins to show temperature rise after the 8th hour but remains below 5°C at the 12th hour, demonstrating longer endurance in maintaining low temperatures.

This explains that. PCM-K has a rapid temperature rise rate after a certain period after 8 hours, which can indicate that PCM-K is effective for cooling for a short time and experiencing heat release afterwards. PCM-N has better stability than PCM-K, with a more gradual temperature rise, making it suitable for applications that require temperature stability below 10°C for longer time durations. PCM-T is most stable at around 0°C all the time and shows only a slight increase at the end of the period. This indicates that PCM-T is better for applications that require fixed temperatures close to freezing over a long period of time.

DISCUSSION

Cooling Box Performance
Canned Drinks (T1)

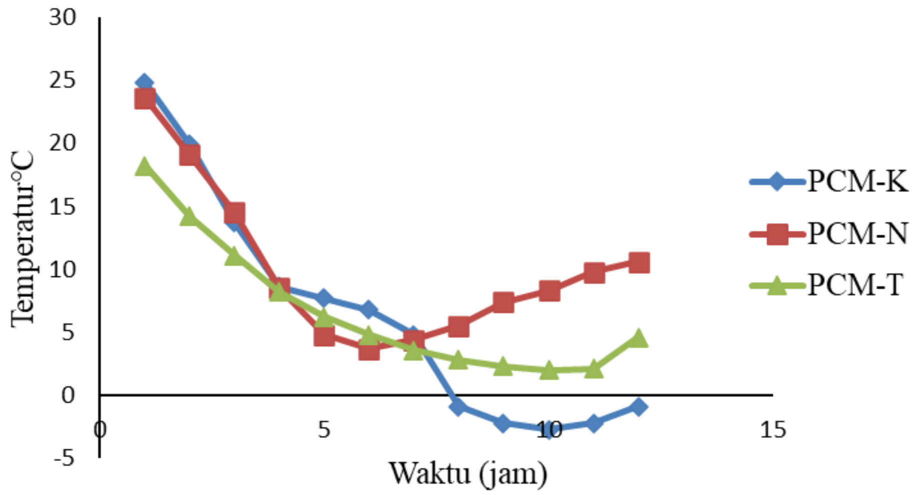

Figure 6. *Graph of Temperature Changes Relative to Time During the Testing Process at Beverage Can Temperature Using PCM-N, PCM-K, and PCM-T*
Source: Researcher (2024)

Based on the test results in the process of comparing beverage cans using PCM-N, PCM-K, and PCM-T As shown in Figure 6 the graph of temperature changes to time during the testing process at the temperature of beverage cans. PCM-K shows a rapid drop in temperature in the first few hours, from about 25°C to almost 0°C in about 5 hours. After reaching its lowest point, the temperature of PCM-K remained stable near 0°C for some time. After about 10 hours, the temperature starts to rise slightly but stays below 5°C until the 12th hour. PCM-N experiences a slower temperature drop than PCM-K and stabilizes at a temperature of around 5-10°C after about 5 hours. After stabilizing for some time, the temperature of PCM-N begins to rise again after 7 hours and tends to continue to rise until it reaches about 10-15°C at the 12th hour.

PCM-T has a slower temperature drop compared to PCM-K and PCM-N is stable at around 5°C within 5 hours. After reaching its lowest point, PCM-T showed a slight increase in temperature but remained lower than PCM-N in the range of 5-10°C until the 12th hour. This shows that PCM-K is most efficient in the initial temperature drop and is able to keep the temperature very low for a long time. This makes it a good choice for applications that require rapid temperature drops and continuous cold temperature maintenance. PCM-T Although the initial temperature drop is faster, PCM-T is able to maintain a positive temperature for longer as compared to PCM-N. This suggests that PCM-T can be a good choice for applications where long-term stable positive temperature maintenance is required. PCM-N is less efficient at lowering the initial temperature than PCM-K and PCM-T but still shows an acceptable temperature drop.

These results explain that PCM-K is more efficient at lowering the temperature rapidly, but PCM-T, is able to maintain positive temperatures for a longer time. This is where a rapid decrease in temperature is required in a short period of time, but a stable temperature at a certain point is more desirable in the long run. In accordance with research that shows that tapioca flour has the ability to withstand temperatures longer compared to KCl and NaCl in refrigeration applications (Williams et al., 2020).

In Styrofoam Chamber (T2)

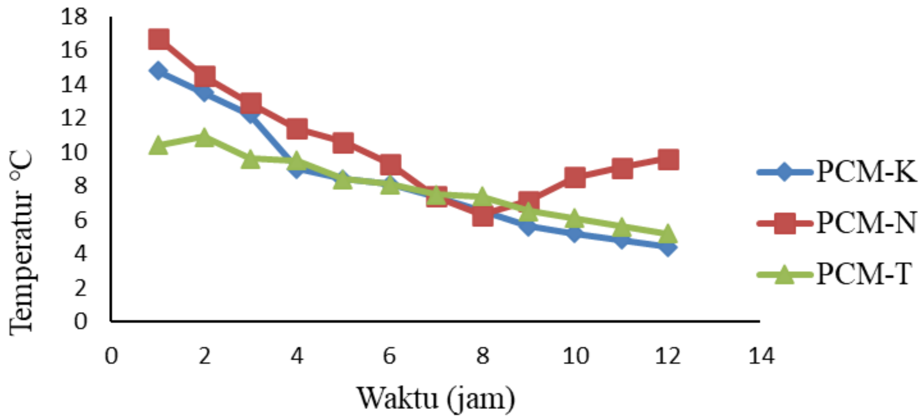

Figure 7. *Graph of Temperature Change Relative to Time During the Testing Process in Styrofoam Chamber Using PCM-K, PCM-N and PCM-T*
Source: Researcher (2024)

Based on the test results in the comparison process in the styrofoam chamber, using PCM-N, PCM-K, and PCM-T As shown in figure 4.12, the graph of temperature changes to time during the testing process in the styrofoam chamber. This shows that PCM-K has the most efficient ability to maintain very low temperatures, indicating that it is suitable for applications that require stable cooling below freezing. PCM-N is less efficient at maintaining cold temperatures, with a fairly rapid increase in temperature. This indicates that PCM-N is more suitable for applications with warmer temperature storage requirements or that do not require extremely cold temperatures. The PCM-T exhibits good temperature stability around freezing, making it ideal for applications where temperatures must be kept close to freezing for long periods of time. These results are consistent with the findings by Nguyen et al. (2019) which show that KCl is very effective in maintaining low temperatures in styrofoam insulation, while NaCl and tapioca flour show good performance in temperature stability over a longer period of time.

Styrofoam Outer Wall (T3)

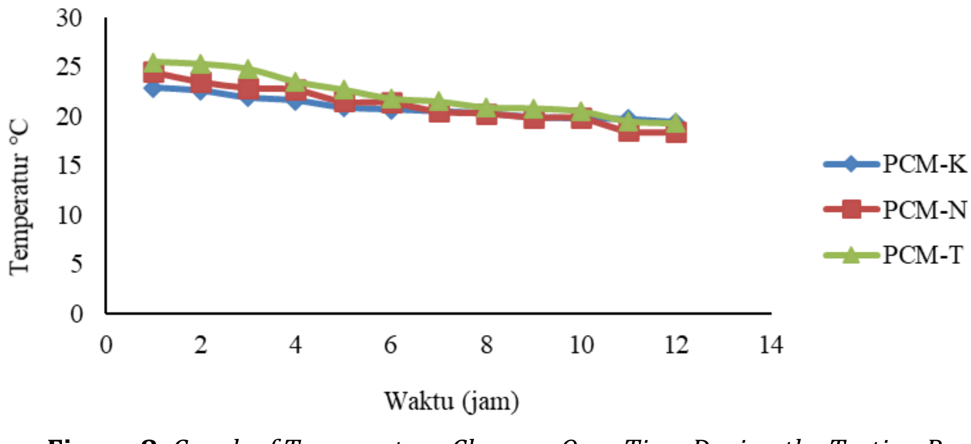

Figure 8. *Graph of Temperature Changes Over Time During the Testing Process of Styrofoam Exterior Walls Using PCM-K, PCM-N and PCM-T*
Source: Researcher (2024)

Based on the test results in the comparison process of the outer wall of styrofoam, using PCM-N, PCM-K, and PCM-T As shown in figure 4.13. graph of temperature change over time during the testing process of the outer wall of styrofoam. In general, all three types of PCM. PCM-K, PCM-N, and PCM-T show similar patterns of temperature decline over time. The initial temperature of the three PCMs starts at around 27°C to 28°C. After that, the temperature gradually decreased until the 12th hour. Comparison of each PCM. The initial temperature of PCM-K is slightly lower than that of other PCMs. Nonetheless, PCM-K consistently showed lower temperatures than PCM-N and PCM-T over 12 hours of observation, suggesting that PCM-K may be more efficient at absorbing or retaining cold temperatures. Whereas PCM-N exhibits a slightly higher temperature than PCM-K but is similar to PCM-T most of the time. The temperature drop of PCM-N is quite stable, indicating that this material is able to maintain a fairly low temperature even though it is not as efficient as PCM-K. And PCM-T has the highest initial temperature, but the temperature drops gradually closer to PCM-K after a few hours. PCM-T appears to exhibit similar thermal characteristics to PCM-N, although it starts at a higher temperature.

The three PCMs show a slow and stable pattern of temperature decline without drastic changes. This indicates that all three are suitable for applications that require stable temperature control over a longer period of time. regarding the ability of the three PCMs to maintain temperature over a certain period of time. Based on the temperature drop pattern, PCM-K appears to be superior in maintaining lower temperatures than PCM-N and PCM-T, indicating the potential for higher efficiency in thermal storage applications. PCM-K can be better suited for use in applications that require lower temperature control, such as food storage, pharmaceutical refrigeration, or other medical applications.

In contrast, PCM-N and PCM-T show similar patterns to each other and tend to maintain temperatures at slightly higher levels. Both of these materials may be more suitable for applications that do not require too low temperatures but require stability over a long period of time. In line with research by Taylor et al. (2023) which shows that KCl performs better in exterior wall applications with a stable temperature drop compared to NaCl and tapioca flour.

CONCLUSION

Based on the charging and disharging testing process for PCM-N, PCM-K, and PCM-T as cooling media, conclusions can be drawn, among others, namely, the best performance in the charging process, namely PCM-N with a temperature of -16°C. PCM-N experienced the fastest temperature drop and experienced a stable temperature increase between PCM-K and PCM-T. The best performance in the discharging process is PCM-K with a temperature of -11.8°C. PCM-K is slower in temperature decline and experiences a faster temperature increase of PCM-N and PCM-T. The best performance among PCM-N, PCM-K, and PCM-T is PCM-K because PCM-K is more efficient in lowering the temperature quickly and is also effective in maintaining temperature. PCM-K also has the best performance in cooling. The optimal solution of PCM-N, PCM-K, and PCM-T in maintaining a longer temperature is, PCM-T is better because it can maintain a more stable and durable temperature than PCM-K and PCM-N.

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